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Application of the Structural Decomposition Analysis to assess the indirect energy consumption and air emission changes related to Italian households consumption

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ABSTRACT

The design of sustainable production and consumption strategies and the assessment of implemented actions require to identify the driving forces that influence the trend of energy consumption and environmental impacts.

For this purpose, the Structural Decomposition Analysis (SDA) was developed as a suitable methodology to analyse the driving forces of the changes in economic, energy and environmental indicators.

The paper presents one of the first Italian studies that apply an energy and environmental extended input–output model, opportunely shaped to the examined context, combined with SDA. In detail, it aims at: (1) investigating the energy use and the air emissions arisen from the productive sectors to meet the household final demand in the period 1999–2006; (2) identifying the sources of variations in energy and environmental indicators; and (3) identifying which economic sectors are the most relevant sources of variation and must to be taken into account in the definition of sustainable production and consumption strategies.

As sources of changes, the authors investigate: energy and emission intensity effects, Leontief effect and final demand effect.

Outcomes point out that the increase of the final consumptions often nullifies the energy and environmental benefits due to the improvement of the eco-efficiency and to the introduction of innovative technologies of production.

The sector level analysis shows that "tertiary" and "electricity, gas and vapour" result the highest Italian consuming sectors of energy. Thus they should be focused for energy saving strategies. "Agriculture, hunting and sylviculture" and "road transports", that are primarily sectors affecting air emissions, should be taken into account for the reduction of environmental impacts.

Results highlight that the current dichotomy of final demand growth and improvement of eco-efficiency represents a key problem that needs to be addressed. Therefore the presented study can aid to define suitable oriented strategies for the energy and environmental impact reduction.

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1. Introduction

Promoting and adopting sustainable production and consumption patterns is a worldwide concern. The items of climate change and energy supply point out that the global community urgently needs to adopt more sustainable lifestyles, to reduce both the consumption of natural resources and the emissions of air pollutants. Specific strategies are needed to improve the environmental performances of goods and services and the energy saving, to develop more efficient technologies, and to address consumers toward more sustainable purchases [1]. This is crucial in order to decouple economic growth from environmental degradation [2].

Before starting the design of new policies and strategies as well as the assessment of implemented measures, knowledge about the factors that drive the evolution of energy consumption and environmental impacts is required [3,4].

For this purpose a suitable approach, known as Decomposition Analysis (DA), was developed to identify and gauge the driving forces which underlie changes in socio-economic, energy and environmental indicators [5]. In detail, two different techniques are able to decompose indicator changes are the Structural Decomposition Analysis (SDA) and the Index Decomposition Analysis (IDA), which are applied to estimate the influence of the economic growth, sector shifts and technology innovation on the above indicators [6,7].

In the following sections, the authors present one of the first Italian application of an energy and environmentally extended input–output model integrated with the SDA methodology, opportunely shaped to the examined context. The goal of the study is threefold. In detail, it aims at: (1) applying an energy and environmental input–output model to quantify the indicators "indirect energy[1] use" and "air emissions" from national economic sectors to meet the final demand of Italian households over the period 1999–2006; (2) applying a complete SDA to assess the key factors which influence the trend of the above indicators, in order to provide some insights for orienting future Italian environmental policies; (3) carrying out a sector level analysis to allocate the changes of the assessed indicators to the different economic sectors and to identify the most significant sources of variation to be taken into account in the definition of sustainable production and consumption strategies.

In detail the paper is organized as follows: Section 2 includes the description of the DA methodology. Section 3 presents a literature review of the two decomposition techniques. Section 4 describes the method used to perform the case study and analyses the data sources. Sections 5 and 6 contain the main results of the developed case study. At the end of the paper, the authors provide some final remarks arisen from the study.

2. Methodological framework of DA

DA is used to assess the effect of driving forces on indicator changes. In detail, the methodology focuses on the analysis of the following driving forces effects [4]:

- Production effect (both IDA and SDA), which gauges the effect of total output change on the assessed indicator.
- Structural effect (only IDA), which measures the effect of a variation in the production shares of economic sectors.
- Leontief effect (only SDA), which assesses the effect, on the variation of the examined indicators, of the changes in the input–output coefficients in the Leontief inverse matrix. It represents a technological effect of changes in the intermediate input structure.
- Intensity effect (both IDA and SDA), a technological effect which measures the incidence of change on the use of the indicators at sector level per unit of output.
- Final demand effect (SDA), which assesses the influence of a variation of the final demand in each economic sector on the considered indicator.

The main differences between the IDA and SDA are related to the applied model and the used data [4].

The SDA approach is based on the input–output coefficients and the final demand from input–output framework. The IDA framework uses data that are at a higher level of aggregation than the input–output tables. It uses the outputs per sector for the economic decomposition.

These basic differences also imply the advantages and the drawbacks of the two methods (Table 1). First of all, the use of IDA allows to assess only the direct impacts of the final demand and is not able to catch indirect demand effect. The indirect demand effect arises when the increase of direct demand in one sector indirectly causes the rise of the demand in other sectors. SDA is able to assess both direct and indirect energy demand [8]. Another advantage of SDA versus IDA is that the former differentiates between technological effects and final demand effects, while the IDA approach has the main advantage to require lower data than SDA. However this involves a less detailed analysis of the economic structure than SDA.

2.1. Applications of IDA and SDA

The application of a DA involves four steps, summarized in the following.

- First step: definition of the indicators to be investigated and the interval of the time for which driving forces have to be analysed. The availability of data is essential for selecting the interval of time to be investigated. SDA studies are often characterized by time periods up to 10 years, since input–output tables are not yearly available for many countries. For IDA studies yearly time periods are common, because the aggregate data at sector level are often available.
- Second step: selection of the indicator form. An indicator can be represented as absolute (for example the energy consumption), as intensity (for example the energy consumption per unit of economic output), and as elasticity (for example the relative change in the indicator divided by the related change in the economic output). The SDA literature generally focuses only on the assessment of absolute changes in the variables, while in the IDA studies the three above forms of indicator could be employed.
- Third step: choice of the mathematical approach for the decomposition process, which can be either additive or multiplicative. The former decomposes the difference between an indicator I at time t and at time $t-1$ into a number (n) of driving force effects

[1] The indicator "indirect energy" represents the energy used by industries to produce goods and services needed to meet the final demand of consumers. Here the term "indirect" is used to distinguish the energy used by industries from that directly used by final users.

Table 1
Advantages and drawbacks of IDA and SDA.

	IDA	SDA
Data requirement	Low	High
Assessed impact (direct/indirect)	Direct	Direct and indirect
Level of detail in the analysis of an economic structure	Low	High
Differentiation between technological and final demand effects	No	Yes

that are related additively.

$$I^t - I^{t-1} = \text{Driving force effect}_1 + \cdots + \text{Driving force effect}_n + \text{Residual}. \tag{1}$$

The latter represents the relative variation of an indicator I decomposing it into (n) driving force effects which are related multiplicatively:

$$\frac{I^t}{I^{t-1}} = \text{Driving force effect}_1 + \cdots + \text{Driving force effect}_n + \text{Residual}. \tag{2}$$

Details about the mathematical form for a decomposition approach can be found in [9] and [4].

- Last step: selection of the indexes to weight driving forces. Several index approaches can be used in decomposition analysis, both in IDA and SDA, as the following ones [9–11]:
  - the Laspeyres index, that uses the weights for the base year;
  - the Paasche index, that uses the weights based on the current year;
  - the Marshall–Edgeworth index, that uses as weight an average of the above two indexes base year weight and the current year weight;
  - the Fisher ideal index, that is obtained by the geometric mean of the Laspeyres and Paasche indexes;
  - the Divisia index, that is a weighed sum of the logarithmic growth rates, where the weights are the components' shares in total value, given in the form of a line integral.Indexes have to be selected depending on the following relevant properties [4,12]:
  - Completeness: the decomposition has no residual. The presence of a residual indicates that the sum of the driving force effects overestimates or underestimates the total changes of the indicator. The decomposition is defined complete when in the additive approach the residual is 0, while in the multiplicative approach is 1.
  - Time reversal: the decomposition gives a reciprocal result if the time period of the driving forces is reversed.
  - Zero value robustness: some indices, as the Divisia one, use logarithms and when there are zero values in the datasets could arise problems in the numerical simulations. The usual adopted solution is to replace zero values by small numbers, so that when it tends to zero the index converges.

2.2. The complete decomposition analysis

In a DA, given a variable P which is dependent on two factors X and Y:

$$P = XY, \tag{3}$$

the variation of P in the time period $(0, t)$ can be decomposed in:

$$\Delta P = P^t - P^0 = X^tY^t - X^0Y^0 = (X^t - X^0)Y^0 + (Y^t - Y^0)X^0 + (X^t - X^0)(Y^t - Y^0) = Y^0\Delta X + X^0\Delta Y + \Delta X\Delta Y, \tag{4}$$

where $Y^0\Delta X$ is the contribution of the X change on the total change in P; $X^0\Delta Y$ is the contribution of the Y change on the total change in P; $\Delta X\Delta Y$ is the residual which depends on both X and Y.

The existence of residual causes an estimation error, in fact it underestimates or overestimates the results of the analysis [13].

To improve the reliability and accuracy of the DA, some authors developed a "complete decomposition analysis" where the residual has been eliminated.

In the following, two models of complete decomposition analysis are illustrated, one developed by Sun [14] both for IDA and SDA, and the other proposed by Dietzenbacher and Los [15,16] specifically for SDA.

Sun proposed an approach to decompose the residual according to the principle of "jointly created and equally distributed" [14]. Thus, considering Eq. (3), the residual term is equally split between X and Y.

The contributions of the two factors to the total change of P become:

$$X_{\text{effect}} = Y_0\Delta X + \left(\frac{1}{2}\right)\Delta X\Delta Y, \tag{5}$$

$$Y_{\text{effect}} = X^0\Delta Y + \left(\frac{1}{2}\right)\Delta X\Delta Y, \tag{6}$$

$$\Delta P = X_{\text{effect}} + Y_{\text{effect}}. \tag{7}$$

Similarly, in a three factors model it is $P = XYZ$ and the contributions of the factors to the total change of P are the following:

$$X_{\text{effect}} = Y^0Z^0\Delta X + \left(\frac{1}{2}\right)\Delta X(Z^0\Delta Y + Y^0\Delta Z) + \left(\frac{1}{3}\right)\Delta X\Delta Y\Delta Z, \tag{8}$$

$$Y_{\text{effect}} = X^0Z^0\Delta Y + \left(\frac{1}{2}\right)\Delta Y(Z^0\Delta X + X^0\Delta Z) + \left(\frac{1}{3}\right)\Delta X\Delta Y\Delta Z, \tag{9}$$

$$Z_{\text{effect}} = X_0Y_0\Delta Z + \left(\frac{1}{2}\right)\Delta Z(Y^0\Delta X + X^0\Delta Y) + \left(\frac{1}{3}\right)\Delta X\Delta Y\Delta Z, \tag{10}$$

$$\Delta P = X_{\text{effect}} + Y_{\text{effect}} + Z_{\text{effect}}. \tag{11}$$

In general, if P has an n-dimensional space,

$$P = X_1X_2X_3\ldots X_n. \tag{12}$$

Thus, its variation can be decomposed in[2]:

$$\begin{aligned}\Delta P = {} & n \text{ terms with one order of } \Delta\,(\Delta X_i,\ i = 1, 2, 3, \ldots n) \\ & + \frac{n(n-1)}{2!}\text{terms with two orders of } \Delta\,(\Delta X_i\Delta X_j,\ i \neq j) \\ & + \frac{n(n-1)(n-2)}{3!}\text{terms with three orders of } \Delta\,(\Delta X_i\Delta X_j\Delta X_r, \\ & i \neq j \neq r) + \cdots + \text{one term } n(n-1)(n-2)\cdots\frac{2\times 1}{n!} \\ & \text{with } n \text{ orders of } \Delta\,(\Delta X_i\Delta X_j\ldots\Delta X_{n-1}\Delta X_n).\end{aligned} \tag{13}$$

The first n items are the effects of each of the n factors, other items are the interactions relative to some factors. The effect for the factor

[2] Details on Eq. (13) can be found in [14].

i is [13,14]:

$$X_{i\text{effect}} = \left(\frac{P^0}{X_i^0}\right)\Delta X_i + \sum_{j \neq i}\left(\frac{P^0}{2X_iX_j}\right)\Delta X_i \Delta X_j + \sum_{j \neq i \neq r}\left(\frac{P^0}{3X_iX_jX_r}\right)\Delta X_i \Delta X_j \Delta X_r + \cdots + \left(\frac{1}{n}\right)\Delta X_1 \Delta X_2 \ldots \Delta X_n. \quad (14)$$

Dietzenbacher and Los [15,16] proposed a model of complete decomposition analysis without residual terms. Such a model does not use a proper single index, but it starts from the two approaches of the Laspeyres and the Paasche indexes and combines them. Therefore, some terms are analysed at the base year and others at the current year. In detail, assuming Laspeyres and Paasche weights for every driving force, if there are n driving forces, there must be $n!$ different complete decompositions as a result of all the possible Laspeyres–Paasche combinations. All these possible forms are equivalent, and no form is to be preferred to the others. Nevertheless, the results of the different forms can differ largely. Dietzenbacher and Los suggested to calculate the average effects of all $n!$ expressions.

Considering Eq. (3), the change in P between two years is:

$$\Delta P = P^t - P^0. \quad (15)$$

Following the approach proposed by Dietzenbacher and Los, the change in P can be decomposed in:

$$\Delta P = X^tY^t - X^0Y^0 = X^tY^t - X^0Y^0 + X^tY^0 - X^tY^0 = \Delta XY^0 + \Delta YX^t, \quad (16)$$

$$\Delta P = X^tY^t - X^0Y^0 = X^tY^t - X^0Y^0 + X^0Y^t - X^0Y^t = \Delta XY^t + \Delta YX^0. \quad (17)$$

As above stated, Eqs. (16) and (17) are equivalent and there is no reason why one decomposition should be preferred to the other. The usual solution is to take the mean of the above expressions:

$$\Delta P = \frac{1}{2}\Delta X(Y^0 + Y^t) + \frac{1}{2}\Delta Y(X^t + X^0). \quad (18)$$

In a three factor model, $P = XYZ$ and the possible combinations that can be used to take the mean are 6 (3!):

$$\Delta P_1 = (\Delta XY^0Z^0) + (X^t\Delta YZ^0) + (X^tY^t\Delta Z), \quad (19)$$

$$\Delta P_2 = (\Delta XY^0Z^0) + (X^t\Delta YZ^t) + (X^tY^0\Delta Z), \quad (20)$$

$$\Delta P_3 = (\Delta XY^tZ^0) + (X^0\Delta YZ^0) + (X^tY^t\Delta Z), \quad (21)$$

$$\Delta P_4 = (\Delta XY^0Z^t) + (X^t\Delta YZ^t) + (X^0Y^0\Delta Z), \quad (22)$$

$$\Delta P_5 = (\Delta XY^tZ^t) + (X^0\Delta YZ^0) + (X^0Y^t\Delta Z), \quad (23)$$

$$\Delta P_6 = (\Delta XY^tZ^t) + (X^0\Delta YZ^t) + (X^0Y^0\Delta Z). \quad (24)$$

In order to simplify the calculation when a variable is dependent on many factors, Dietzenbacher and Los suggest that the mean of the solutions ΔP_1 and ΔP_6, called "polar decompositions", can be a suitable approximation to the mean of all decompositions.

In general, if P is dependent on n factors (F) it is equal to:

$$P = F_1 \times F_2 \times \cdots \times F_n. \quad (25)$$

Two polar decompositions are the following:

$$\Delta P = \Delta F_1 F_2^t F_3^t \ldots F_{n-1}^t F_n^t + F_1^0 \Delta F_2 F_3^t \ldots F_{n-1}^t F_n^t + F_1^0 F_2^0 F_3^0 \ldots \Delta F_{n-1} F_n^t + F_1^0 F_2^0 F_3^0 \ldots \Delta F_{n-1}^0 \Delta F_n, \quad (26)$$

$$\Delta P = \Delta F_1 F_2^0 F_3^0 \ldots F_{n-1}^0 F_n^0 + F_1^t \Delta F_2 F_3^0 \ldots F_{n-1}^0 F_n^0 + F_1^t F_2^t F_3^t \ldots \Delta F_{n-1} F_n^0 + F_1^t F_2^t F_3^t \ldots \Delta F_{n-1}^t \Delta F_n. \quad (27)$$

3. Literature review

One of the first studies on DA goes back to the late 1970s [10]. It was proposed to assess the impacts of structural changes and sector energy intensity changes on energy use in industry. Since then, several studies have been performed and now both IDA and SDA represent widely accepted analytical tools to support the definition of energy and environmental policies [17,18].

Literature about IDA has widely studied the implications of index theory and the specification of the decomposition, defining a function relating the aggregate to be decomposed in a number of defined factors of interest. Literature on SDA has paid attention on distinguishing a large number of driving force effects [4].

Chang and Lin [19] applied SDA to analyse the changes in factors that influence the industrial greenhouse gas (GHG) emissions in Taiwan by decomposing the emissions into a number of driving forces over the decade 1981–1991. The cited study highlighted that the increase of GHG emissions mainly depended on the growth of domestic final demand and of exports, while the increasing rate of added value had a less influencing effect. The effect of a decreasing industrial GHG intensity, measured as GHG emission amount to primary input, at industrial level is the main reducing factor, followed by the structure of domestic final demand. Similar results have been obtained for the period 1989–2004 [20].

Weber [21] used the DA to assess the driving forces of US energy use changes from 1997 to 2002. Results showed that the growing population and household consumption caused the rise of the energy demand, but such a rise was offset by considerable structural changes within the economy. In fact, US economy moved from manufacturing sectors toward services and construction sectors, and from more energy-intensive to less energy-intensive manufacturing sectors.

Papagiannaki and Diakoulaki [22] applied the IDA to assess the trend of the CO_2 emissions from passenger cars in Denmark and Greece for the period 1990–2005. Population, cars per capita, fuel mix, yearly covered distances, engine power and technology were the analysed factors. The results were similar both for Greece and Denmark. Number of vehicles per capita is the most influencing factor while the effects of the other factors are quite lower. However, in Denmark the number of vehicles per capita tends to increase at a much low pace.

Muñoz and Hubacek [23] combined the SDA and the Material Flow Accounting (MFA) methodology to analyse the driving forces of the material consumption in Chile over the decade 1986–1996. The variations in MFA were broken down into effects caused by the following changes:

- changes in resource use per unit of output (material intensity effect);
- changes among and within sectors (structural change effect);
- changes in the composition of the final demand (mix effect);
- changes due to shifting shares of domestic final demand and export categories (category effect);
- changes in the overall level of economic activities (level effect).

The results point out that economic growth, material intensity and category effects are the main sources of changes in material consumptions.

Lim et al. [24] applied the input–output SDA to investigate the sources of changes in Korean CO_2 emissions from industrial

sectors during 1990–1995, 1995–2000, and 2000–2003. The analysis involved eight factors: changes in emission coefficients caused by shifts in energy intensity and carbon intensity, changes in economic growth, structural changes (in domestic final demand, exports, imports of final and intermediate goods, and production technology). The trend showed was the growth of CO_2 emissions for all the three assessed periods, even if the rate of growth decreased from 1998. In the first period (1990–1995) all the examined factors contributed to rise emissions, except for imports of final and intermediate products. In the second period (1995–2000) the increase was mainly due to economic growth, exports and intermediate imports and in the third period (2000–2003) was due to energy intensity, economic growth and intermediate imports. Among all the involved factors, economic growth gave the most high contribution to CO_2 emission increase.

Wachsmann et al. [25] identified the driving forces determining the changes in energy use by industry and households in the Brazilian economy from 1970 to 1996. By means of SDA energy use was decomposed into eight factors, among which changes in wealth, population and sectors interrelations caused the increase of energy use, while changes in direct energy intensity and in per capita household energy consumption reduced energy use.

Paul and Bhattacharya [13] applied DA to identify four sources of change in the energy-related CO_2 emissions in India over the period 1980–1996: emission factors, energy intensity, structural changes and economic activities. The results showed that economic growth had the largest positive effect on CO_2 emissions changes in all the economic sectors.

Marra Campanale [26] applied both IDA and SDA to examine the historical changes in Italian air emissions (carbon dioxide and acidifying substances) from productive sectors in the period 1992–2003, starting from the Italian NAMEA data. The total change, that was an increase in production-related CO_2 emissions of about 10%, was decomposed into three driving forces. Outcomes of the study showed that the production (65.9%) and intensity of emission (−61.2%) factors almost had an opposite effect on the total change; the production structure had a positive effect on the air emissions (5.4%).

4. Case study: the application of SDA to the Italian contest

In this section a complete input–output SDA is applied to analyse the variations of the indicators “indirect energy consumption” and “indirect air emissions” caused by the Italian production sectors to meet the final demand of households in the period 1999–2006. The SDA technique allows to decompose the above indicators into three driving forces: intensity effect, Leontief effect, final demand effect.

In particular, the authors apply the two approaches discussed in Section 2.2.

The starting point of the analysis is the standard representation of the input–output model, in the matrix notation [27–29]:

$$X = (I - A)^{-1} Y_f, \tag{28}$$

where X is the vector $(n \times 1)$ of the production in all sectors; Y_f is the vector $(n \times 1)$ of household final demand; A is the technological coefficient matrix $(n \times n)$ (which components represent the inputs used by industries to produce one unit of output); and I is the identity matrix.

Although the input–output model involves the assumptions of constant technological coefficients[3] and a linear production function,[4] it represents a valid method to provide a reliable description of an economy in the short time [30–32]. The indirect energy consumption and the air emissions from the Italian economic sectors can be calculated as products of their driving forces, assuming that all the driving forces are independent each other.[5]

In detail, the matrix of indirect energy consumption of Italian economic sectors (E) is expressed as follows:

$$E = E'(I - A)^{-1} Y_f, \tag{29}$$

where E' is the energy intensity matrix; it represents the energy used per unit of output; $(I - A)^{-1}$ is the inverse of the Leontief matrix; and Y_f is the vector of Italian household final demand.

Analogously, the matrix of air emissions from industries (B) is expressed as follows:

$$B = B'(I - A)^{-1} Y_f, \tag{30}$$

where B' is the emission intensity matrix; it represents the emission generated per unit of output; $(I - A)^{-1}$ is the inverse of Leontief matrix; Y_f is the vector of Italian household final demand.

Each item on the right-hand side of Eqs. (29) and (30) represents a driving force.

The application of the SDA to the examined context, following the approach proposed by Sun [14] and according to Eq. (11), implies that the changes in the above indicators can be written as follow:

$$\Delta E = E'_{\text{effect}} + L_{\text{effect}} + Y_{f\text{-effect}}, \tag{31}$$

$$\Delta B = B'_{\text{effect}} + L_{\text{effect}} + Y_{f\text{-effect}}. \tag{32}$$

The contribution of the first item of Eq. (31) to the variation of the indicator E is defined “energy intensity effect” (E'_{effect}). It represents the influence that a change in the energy use per unit of monetary output has on the indirect energy consumption. A negative value of E'_{effect} reveals an improvement of energy efficiency in the economic sectors.

The contribution of the first item in Eq. (32) in the variation of indicator B, defined “emission intensity effect” (B'_{effect}), relates to the effect on the indirect air emissions caused by the variation of pollutant emission per unit of monetary output. An improvement of eco-efficiency is pointed out by a negative value of B'_{effect}.

The influence of the second item of either Eqs. (31) and (32) on the changes in the indicators E and B is the so-called “Leontief effect” (L_{effect}), that analyses the impact on each examined indicator due to a variation in the use of monetary input per unit of monetary output. A negative value of L_{effect} relates to a reduction in the use of intermediate inputs in the productive structure.

The incidence of the last item of Eqs. (31) and (32) on the changes in the indicators E and B is defined as “final demand effect” ($Y_{f\text{-effect}}$). It describes the effect of the variation of final household consumption on the examined indicator.

Following the method proposed by Dietzenbacher and Los [15,16], the incidence of the driving forces on the variation of each examined indicators can be calculated as mean of 6 equations, obtained applying Eqs. (19)–(24). In detail, Eqs. (33)–(38) and (39)–(44) allow to assess the driving forces that influence the changes in the indirect energy consumption and indirect emissions, respectively:

$$\Delta E_1 = (\Delta E'(I - A)^0 Y_t^0) + (E'^t \Delta(I - A) Y_f^0) + (E'^t (I - A)^t \Delta Y_f), \tag{33}$$

[3] The amount of input necessary to produce one unit of output is assumed to be constant in the short term, regardless to price effects, changes in technology or economies of scale.

[4] The input–output process assumes that if the output level of an industry changes, the input requirements will change proportionally.

[5] The assumption of independence of driving forces is not always true in the real world. For example, an increase of the final demand can imply a change in the productive structure and cause a reduction of indirect energy consumption per unit of produced output.

$$\Delta E_2 = (\Delta E'(I-A)^0 Y_f^0) + (E'^t \Delta(I-A) Y_f^t) + (E'^t (I-A)^0 \Delta Y_f), \quad (34)$$

$$\Delta E_3 = (\Delta E'(I-A)^t Y_f^0) + (E'^0 \Delta(I-A) Y_f^0) + (E'^t (I-A)^t \Delta Y_f), \quad (35)$$

$$\Delta E_4 = (\Delta E'(I-A)^0 Y_f^t) + (E'^t \Delta(I-A) Y_f^t) + (E'^0 (I-A)^0 \Delta Y_f), \quad (36)$$

$$\Delta E_5 = (\Delta E'(I-A)^t Y_f^t) + (E'^0 \Delta(I-A) Y_f^0) + (E'^0 (I-A)^t \Delta Y_f), \quad (37)$$

$$\Delta E_6 = (\Delta E'(I-A)^t Y_f^t) + (E'^0 \Delta(I-A) Y_f^t) + (E'^0 (I-A)^0 \Delta Y_f), \quad (38)$$

$$\Delta B_1 = (\Delta B'(I-A)^0 Y_f^0) + (B'^t \Delta(I-A) Y_f^0) + (B'^t (I-A)^t \Delta Y_f), \quad (39)$$

$$\Delta B_2 = (\Delta B'(I-A)^0 Y_f^0) + (B'^t \Delta(I-A) Y_f^t) + (B'^t (I-A)^0 \Delta Y_f), \quad (40)$$

$$\Delta B_3 = (\Delta B'(I-A)^t Y_f^0) + (B'^0 \Delta(I-A) Y_f^0) + (B'^t (I-A)^t \Delta Y_f), \quad (41)$$

$$\Delta B_4 = (\Delta B'(I-A)^0 Y_f^t) + (B'^t \Delta(I-A) Y_f^t) + (B'^0 (I-A)^0 \Delta Y_f), \quad (42)$$

$$\Delta B_5 = (\Delta B'(I-A)^t Y_f^t) + (B'^0 \Delta(I-A) Y_f^0) + (B'^0 (I-A)^t \Delta Y_f), \quad (43)$$

$$\Delta B_6 = (\Delta B'(I-A)^t Y_f^t) + (B'^0 \Delta(I-A) Y_f^t) + (B'^0 (I-A)^0 \Delta Y_f). \quad (44)$$

In the above equations:

- E'_{effect} is the mean of the first items of Eqs. (33)–(38);
- B'_{effect} is the mean of the first items of Eqs. (33)–(38);
- L_{effect} is the mean of the second items of Eqs. (33)–(38) for the energy analysis and of the second items of Eqs. (39)–(44) for the environmental analysis;
- $Y_{f\text{-effect}}$ is the mean of the third items of Eqs. (33)–(38) for the energy analysis and of the third items of Eqs. (39)–(44) for the environmental analysis.

The application of the two above methods allowed to obtain the same results.

4.1. Sources of data

Three types of data are required for the application of the input–output SDA: (1) input–output tables recording the monetary interrelations among the sectors of an economy; (2) physical data on energy consumption; and (3) physical data on air emissions.

The input–output tables applied in the study include 59 economic sectors. They are derived by Italian supply and use tables developed by the Italian Statistical Office ISTAT [33].

Authors deflated the supply and use tables into the constant prices of the base year 1999, using specific indices arranged starting from supply and use tables at current prices and at prices of the precedent year.[6] Further details on the deflation procedure can be found in Cellura et al. [34].

The tables of energy consumptions by industries are based on the yearly data from National Energy Balance developed by the Italian Department of the Economic Development [35]. The Italian energy tables take into account 20 economic sectors and 22 types of energy sources in physical units. The classifications of sectors of the input–output tables and of the National Energy Balance are not identical, thus the authors combine them into 18 economic sectors, starting from information provided by the Italian Department of Economic Development.

Authors derived data on air emissions by the Italian National Accounting Matrix including Environmental Accounts (NAMEA) tables [36], published by ISTAT, that distinguish nine pollutant gases: carbon dioxide ($CO_{2\text{fossil}}$), methane (CH_4), sulphur oxides (SO_x), nitrous oxide (N_2O), ammonia (NH_3), carbon monoxide (CO), nitrogen oxides (NO_x), nonmethane volatile organic compounds (NMVOC), and particulate (PM10).

[6] Thus, all input–output tables were valued at base prices of 1999.

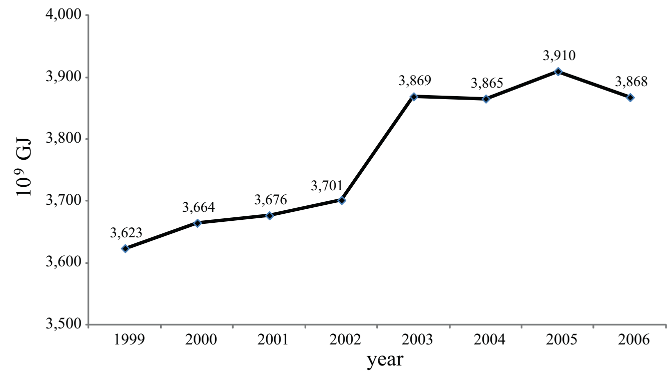


Fig. 1. Indirect energy consumption (1999–2006).

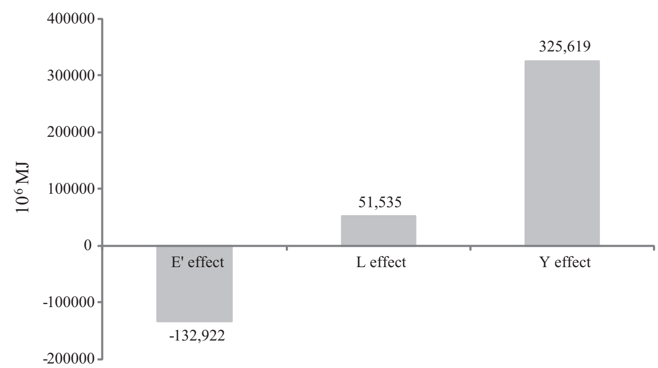


Fig. 2. SDA of indirect energy consumption (1999–2006).

5. Results of the energy SDA

Eq. (29) was applied to the Italian economy to assess the indirect energy consumption in the productive sectors to meet the household final demand of goods and services. Outcomes show an overall increasing trend of indirect energy consumption in the period 1999–2006, except for the periods 2003–2004 and 2005–2006, which are characterized by a decrease (Fig. 1).

The application of SDA, following the approaches proposed by Sun (Eq. (31)) and Dietzenbaches and Los (Eqs. (33)–(38)), highlights that the increase of the indirect energy consumption during 1999–2006 is mainly due to the $Y_{f\text{-effect}}$ (+133%) and partially to the L_{effect} (21%), while the E'_{effect} causes a reduction of the consumption (−54%) (Fig. 2).

Fig. 3 illustrates the variation of indirect energy consumption between two consecutive years from 1999 to 2006. It can be observed that:

- For each two-year period the $Y_{f\text{-effect}}$ increases energy consumption.
- The E'_{effect} reduces energy consumption, except for the periods 1999–2000 and 2002–2003.
- The L_{effect} increases energy consumption, except for the periods 1999–2000, 2003–2004 and 2005–2006.

Table 2 illustrates the results of SDA related to the changes in indirect energy consumption at sector level for the overall period. These results are obtained applying the Sun approach, that allows to carry out a sector level analysis.

E'_{effect} contributes to a reduction of the energy use for each sector, except for “agriculture, hunting and sylviculture” (+18% on the

Table 2
SDA of changes in indirect energy consumption by sector during 1999–2006.

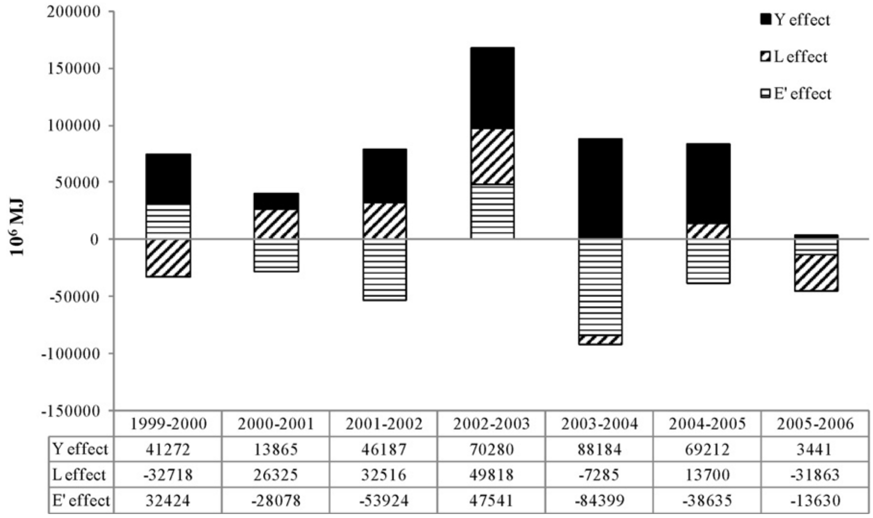
	E'_{effect} [10^6 MJ]	L_{effect} [10^6 MJ]	Y_{effect} [10^6 MJ]	ΔE per sector [10^6 MJ]
Agriculture, hunting and sylviculture	1952	817	8230	11,000
Fishing	638	820	158	1616
Mining	−3.8	0.4	7.2	4
Food and beverages	−16,877	1933	43,784	28,839
Textile and clothing	−7442	−11,932	8843	−10,531
Other manufacturing	−4824	−2784	6597	−1011
Paper and graphics	−1955	−1449	3366	−37
Chemistry and petrochemical	−11,016	−857	−25,944	−37,817
Building materials, glass and ceramic	−1110	−148	1432	174
Metallurgy	−151	−120	−3204	−3475
Mechanics	−5031	−5635	11,825	1159
Construction	−869	273	−1634	−2230
Electricity, gas and vapour	−34,462	8480	92,832	66,851
Tertiary	−8620	61,125	85,923	138,428
Public administration	−55	169	−376	−262
Road transports	−63,280	636	77,828	15,184
Water transports	−103	785	−961	−279
Air transports	20,287	−579	16,913	36,621
ΔE total [10^6 MJ]	−132,922	51,535	325,619	244,233

Table 3
SDA of changes in indirect energy consumption by energy source during 1999–2006.

	E'_{effect} [10^6 MJ]	L_{effect} [10^6 MJ]	Y_{effect} [10^6 MJ]	ΔE per energy source [10^6 MJ]
Coal	100,413	8826	21,820	131,059
Brown coal	−311	7.5	16	−287
Natural gas	169,710	24,614	90,177	284,501
Biomass	28,598	567	2654	31,819
Electricity	31,785	−1220	30,276	60,842
Coke oven coke	−9513	−1926	1434	−10,005
Coke oven gas	−1641	274	849	−519
Products derived from gas	−115	2.1	4.2	−109
Blast-furnace gas	−1868	772	2213	1117
L.P.G.	−24,619	1847	5336	−17,436
Residual gas from refining	−642	−5735	−643	−7020
Light distilled petrol	−1172	−76	4.8	−1243
Gasoline	−198,342	20,614	42,601	−135,128
Jet kerosene	36,655	−26,172	18,909	29,392
Petroleum	−1664	40	92	−1532
Gas oil	83,430	17,882	65,231	166,543
High sulphur fuel oil	−190,108	3452	13,576	−173,080
Low sulphur fuel oil	−156,379	7920	29,481	−118,977
Petroleum coke	1102	−228	1451	2325
Nonenergetic petroleum products	1760	73	138	1971
ΔE total [10^6 MJ]	−132,922	51,535	325,619	244,233

Table 4
SDA of changes in indirect CO_2 emissions by sector during 1999–2006.

	CO_2 [tons]			
	B'_{effect}	L_{effect}	$Y_{f\text{-effect}}$	ΔB per sector
Agriculture, hunting and sylviculture	19,987	2435	466,080	488,502
Fishing	50,728	42,808	10,784	104,320
Mining	−81	41	845	805
Food and beverages	−1,121,700	−212,673	2,370,660	1,036,287
Textile and clothing	−642,369	−1,058,720	594,389	−1,106,699
Other manufacturing	−222,693	−295,909	372,028	−146,574
Paper and graphics	−95,649	−118,857	182,234	−32,273
Chemistry and petrochemical	−1,967,196	−165,360	−1,861,707	−3,994,263
Building materials, glass and ceramic	−38,846	6180	148,615	115,948
Metallurgy	−58,000	−9951	−199,959	−267,910
Mechanics	−605,484	−402,623	631,657	−376,449
Construction	−15,312	22,018	−125,031	−118,324
Electricity, gas and vapor	−1,020,761	552,661	6,188,427	5,720,327
Tertiary	−240,555	2,631,345	4,882,389	7,273,179
Public administration	−9713	7819	−19,719	−21,613
Road transports	1,031,321	−11,182	1,389,502	2,409,641
Water transports	−246,397	39,075	−231,279	−438,602
Air transports	170,523	−42,953	893,514	1,021,084
ΔB total [tons]	−5,012,197	986,155	15,693,427	11,667,385



	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006
Y effect	41272	13865	46187	70280	88184	69212	3441
L effect	-32718	26325	32516	49818	-7285	13700	-31863
E' effect	32424	-28078	-53924	47541	-84399	-38635	-13630

Fig. 3. SDA of indirect energy consumption between two consecutive years (1999–2006).

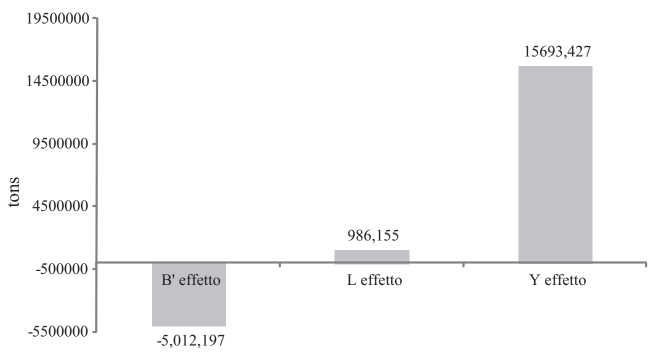


Fig. 4. SDA of indirect $CO_{2fossil}$ emissions (1999–2006).

total change on energy consumed by this sector), "fishing" (+39%) and "air transports" (+55%). For these sectors the positive values point out that they do not use energy efficiently. The negative values for the most of the sectors imply a reduction of indirect energy consumption per unit of output. This reduction indicates that, in the examined period, there was a shifts toward industries with less intensive energy use.

L_{effect} causes a reduction in indirect energy consumption for almost the half of the sectors. This means that the other half of sectors is characterized by an increase of technological input use per unit of output. $Y_{f\text{-effect}}$ causes a decrease of indirect energy consumption only in five sector: "chemistry and petrochemical" (−69%), "metallurgy" (−92%), "construction" (−73%), "public administration" (−143%) and "water transport" (−344%).

The highest increase of indirect energy consumption is in the "tertiary sector", followed by the "electricity, gas and vapour", essentially due to the $Y_{f\text{-effect}}$ and the L_{effect}. E'_{effect} partially offsets the increase by a negative value.

The sectors of "chemistry and petrochemical" and "textile and clothing" undergo a decrease of the energy use in the assessed period. In particular, all the three driving forces cause a negative effect for the first sector; for the second one only the $Y_{f\text{-effect}}$ increases the energy use, but it is totally counterbalanced by the E'_{effect} and the L_{effect}.

Table 3 illustrates the variation of the indirect energy consumption by source from 1999 to 2006. In the examined period, a relevant reduction in the use of gasoline, and high and low sulphur fuel oil can be noted, due to a negative value of E'_{effect}, that offsets totally L_{effect} and the $Y_{f\text{-effect}}$. All the three examined driving forces increase the consumption of coal, natural gas and gas oil.

$Y_{f\text{-effect}}$ increase the consumption of other sources as jet kerosene, residual gas from refining and electricity, partially offset by L_{effect}. E'_{effect} causes a reduction in the most of the energy sources.

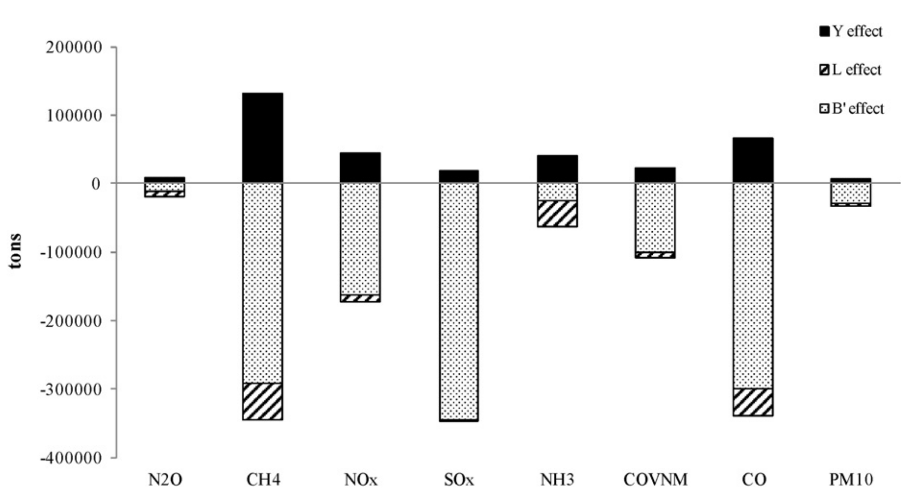


Fig. 5. SDA of indirect air emissions (1999–2006).

Table 5
SDA of changes in indirect N_2O and CH_4 emissions by sector during 1999–2006.

	N_2O [tons]				CH_4 [tons]			
	B'_{effect}	L_{effect}	$Y_{f\text{-effect}}$	ΔB per sector	B'_{effect}	L_{effect}	$Y_{f\text{-effect}}$	ΔB per sector
Agriculture, hunting and sylviculture	−887	−142	2878	1849	−17,119	−1275	30,184	11,791
Fishing	−10	−11	0.9	−20	−202	27	13	−162
Mining	0.001	−0.01	0.07	0.06	−35	−0.08	17	−18
Food and beverages	−1655	−3719	3604	−1770	−34,260	−37,058	41,380	−29,938
Textile and clothing	−534	−943	148	−1328	−8637	−10,157	2180	−16,614
Other manufacturing	−378	−129	77	−430	−3761	−623	1064	−3320
Paper and graphics	−147	−125	26	−246	−2558	−1049	448	−3159
Chemistry and petrochemical	−5021	−87	−700	−5809	−14,391	−1957	−4348	−20,695
Building materials, glass and ceramic	−6.4	−7.9	11	−3.6	−861	−69	111	−819
Metallurgy	−14	−7.1	−17	−37	−249	−22	−331	−603
Mechanics	−262	−190	79	−373	−5247	−1600	1533	−5313
Construction	−38	−18	−15	−71	−1364	−125	−250	−1738
Electricity, gas and vapor	−42	−12	98	43	−36,285	3036	13,105	−20,145
Tertiary	−3361	−2009	1654	−3716	−160,366	−2023	44,126	−118,263
Public administration	−5.8	−4.8	−6	−17	−176	−1.6	−101	−278
Road transports	−32	−100	194	62	−4847	−52	2204	−2695
Water transports	−16	0.23	−22	−38	−279	125	−278	−432
Air transports	−14	−11	38	13	−609	−66	549	−125
ΔB total [tons]	−12,424	−7515	8048	−11,891	−291,245	−52,888	131,607	−212,526

Table 6
SDA of changes in indirect NOx and SOx emissions by sector during 1999–2006.

	NO_x [tons]				NO_x [tons]			
	B'_{effect}	L_{effect}	$Y_{f\text{-effect}}$	ΔB per sector	B'_{effect}	L_{effect}	$Y_{f\text{-effect}}$	ΔB per sector
Agriculture, hunting and sylviculture	−6747	−93	4226	−2615	−2616	−41	432	−2225
Fishing	689	−4.2	108	792	−666	61	8	−597
Mining	−2.2	0.05	2.4	0.27	−4.0	0.1	1.2	−2.8
Food and beverages	−18,883	−5102	8826	−15,159	−22,564	−431	3099	−19,896
Textile and clothing	−7299	−2761	1194	−8866	−19,234	−2331	904	−20,661
Other manufacturing	−3438	−792	800	−3431	−7746	−1133	679	−8201
Paper and graphics	−1979	−242	278	−1943	−4535	−297	224	−4608
Chemistry and petrochemical	−6450	−443	−2983	−9875	−39,714	−129	−6334	−46,177
Building materials, glass and ceramic	−1438	159	336	−943	−1457	111	184	−1162
Metallurgy	−261	−15	−329	−605	−587	−37	−308	−932
Mechanics	−5518	−1057	1298	−5277	−9696	−837	905	−9628
Construction	−1346	36	−325	−1634	−1743	−43	−165	−1951
Electricity, gas and vapor	−32,391	1353	6383	−24,655	−128,946	867	13,871	−114,209
Tertiary	−60,403	172	15,120	−45,111	−90,472	3503	6862	−80,107
Public administration	−85	2.5	−62	−144	−202	12	−28	−218
Road transports	−15,521	−164	6973	−8712	−7848	−185	968	−7064
Water transports	−3663	85	−3178	−6755	−7375	72	−3031	−10,334
Air transports	2142	−202	4533	6473	−403	−78	438	−43
ΔB total [tons]	−162,593	−9067	43,200	−128,460	−345,808	−916	18,708	−328,016

Table 7
SDA of changes in indirect NH_3 and NMVOC emissions by sector during 1999–2006.

	NH_3 [tons]				NMVOC [tons]			
	B'_{effect}	L_{effect}	$Y_{f\text{-effect}}$	ΔB per sector	B'_{effect}	L_{effect}	$Y_{f\text{-effect}}$	ΔB per sector
Agriculture, hunting and sylviculture	−6844	−697	15,388	7848	−3396	−154	1838	−1711
Fishing	−15	−52	2.5	−65	−273	10	23	−240
Mining	−0.02	−0.05	0.05	−0.02	0.29	−0.04	1.2	1.5
Food and beverages	−10,484	−19,639	18,582	−11,542	−9096	−2587	6482	−5201
Textile and clothing	−955	−4397	567	−4785	−10,368	−2505	1764	−11,109
Other manufacturing	−206	−180	177	−208	−3039	−1076	1574	−2540
Paper and graphics	−125	−460	69	−517	−1955	−296	409	−1842
Chemistry and petrochemical	−233	−494	−274	−1000	−2880	−452	−3419	−6751
Building materials, glass and ceramic	−11	−10	6.4	−15	−178	−13	36	−155
Metallurgy	−10	−18	−32	−61	−405	−16	−425	−846
Mechanics	−223	−652	179	−696	−7633	−1135	1530	−7239
Construction	−41	−51	−25	−117	−434	−111	−268	−813
Electricity, gas and vapor	−34	101	80	147	−3382	374	1978	−1031
Tertiary	−6865	−10,310	5375	−11,800	−48,914	346	8657	−39,911
Public administration	−15	−25	−22	−62	−98	2.9	−31	−127
Road transports	−251	−368	285	−334	−7168	−368	1799	−5737
Water transports	−32	−21	−76	−129	−837	82	−565	−1320
Air transports	−28	−59	67	−19	−147	−58	437	231
ΔB total [tons]	−26,371	−37,332	40,348	−23,355	−100,203	−7957	21,820	−86,340

Table 8
SDA of changes in indirect CO and PM10 emissions by sector during 1999–2006.

	CO [tons]				PM10 [tons]			
	B'_{effect}	L_{effect}	$Y_{f\text{-effect}}$	ΔB per sector	B'_{effect}	L_{effect}	$Y_{f\text{-effect}}$	ΔB per sector
Agriculture, hunting and sylviculture	−2244	−633	15,825	12,948	−1189	−65	1701	447
Fishing	−163	3.2	51	−109	75	−2.9	12	84
Mining	−1.9	−0.08	1.5	−0.5	−0.43	0.01	0.29	−0.13
Food and beverages	−17,495	−19,905	21,973	−15,427	−3268	−2123	2461	−2931
Textile and clothing	−17,363	−5557	1532	−21,388	−1462	−610	169	−1902
Other manufacturing	−7988	−1625	1254	−8359	−682	−132	118	−696
Paper and graphics	−3930	−545	318	−4157	−359	−56	35	−380
Chemistry and petrochemical	−9553	−2031	−2699	−14,282	−1977	−144	−375	−2496
Building materials, glass and ceramic	−590	114	186	−290	−43	22	51	30
Metallurgy	−1505	2.7	−2344	−3847	−117	−1.0	−132	−251
Mechanics	−16,819	−3775	3156	−17,438	−1134	−252	230	−1156
Construction	−2344	−161	−396	−2901	−210	11	−58	−257
Electricity, gas and vapor	−5130	1269	2470	−1392	−5466	180	628	−4658
Tertiary	−179,556	−6783	20,178	−166,161	−10,293	−394	2049	−8637
Public administration	−680	−11	−155	−846	−17	−0.50	−8.5	−26
Road transports	−29,412	−535	5690	−24,257	−2559	−44	764	−1839
Water transports	−3412	110	−2219	−5521	−364	11	−380	−733
Air transports	−488	−313	1196	396	−52	−23	67	−7.9
ΔB total [tons]	−298,675	−40,375	66,018	−273,032	−29,118	−3623	7332	−25,409

6. Results of the air emissions SDA

The application of Eq. (30) shows that from 1999 to 2006 the indirect $CO_{2fossil}$ emissions were increased of 6%, rising from 1.97×10^8 tons to 2.1×10^8 tons.

The SDA results for the nine pollutant emissions specified in Section 4.1 are presented. They were obtained applying Eqs. (32) and (39)–(44).

The results illustrated in Fig. 4 point out that the $Y_{f\text{-effect}}$ is the most influencing factor on the variation of $CO_{2fossil}$ emissions in Italy for the period (+135%). It is evident that the "benefit" due to the emission intensity (−43%) is much larger than the "loss" by the L_{effect} (+8%).

A sector level analysis, carried out applying Eq. (32), shows that the $Y_{f\text{-effect}}$ drives a reduction of the $CO_{2fossil}$ emissions for "chemistry and petrochemical" (−46%), "metallurgy" (−75%), "construction" (−105%), "public administration" (−91%), and "water transports" (−37%) (see Table 4). In these sectors a reduction of $CO_{2fossil}$ emissions is also caused by B'_{effect}, maybe due to the adoption of more eco-efficient technologies.

The positive value of the $Y_{f\text{-effect}}$ is totally offset by the B'_{effect} and the L_{effect} for the sectors of "textile and clothing", "other manufacturing", "paper and graphics" and "mechanics".

Similarly to the energy SDA, the most relevant increase of indirect $CO_{2fossil}$ emissions is in the "tertiary" and "electricity, gas and vapour" sectors, followed by "food and beverage" and "road transports".

The sectors of "agriculture, hunting and sylviculture", "fishing", and "road and air transports" result $CO_{2fossil}$ intensive and they should be oriented in the adoption of more eco-efficient technologies of production.

Fig. 5 illustrates the SDA results for the remaining eight air emissions (N_2O, CH_4, NO_x, SO_x, NH_3, NMVOC, CO, and PM10), which trend is decreasing during 1999–2006. Such a trend is essentially due to the B'_{effect}, that offsets the increasing effect of the final demand. As illustrated in Fig. 5, the contribution of the L_{effect} to the air emission reduction is much lower than the B'_{effect}.

A sector level analysis (Tables 5–8) shows that emission intensity implies a negative effect for the most of the sectors, except for "fishing", which is characterized by a positive B'_{effect} on the emission of NO_x (+87%), and PM10 (+89%), "mining", with a positive B'_{effect} on the emission of N_2O (+2%) and NMVOC (+19%), and "air transport", with a positive B'_{effect} on the emissions of NO_x (+33%).

"Agriculture, hunting and sylviculture" results the most impacting sector in the emissions of N_2O, CH_4, NH_3, CO and PM10, while the "air transports" sector involves the highest emissions of NO_x and NMVOC. For these sectors the $Y_{f\text{-effect}}$ offsets the negative contribution caused by the B'_{effect} and the L_{effect}.

In all the examined sectors SO_x emissions decrease, mainly depending on the reduction of the use of fuels with a large content of sulphur.

7. Conclusions

The presented study applies an energy and environmental input–output model integrated with a complete SDA. It is one of the first Italian researches aimed at assessing the trend of the indicators "indirect energy consumption" and "air emissions" of nine pollutants related to the Italian household final demand during 1999–2006, and at identifying the driving forces which determine the changes in the assessed indicators.

In detail, the driving forces under study are: energy intensity effect (for energy SDA), emission intensity effect (for air emissions SDA), Leontief and final demand effects (both for energy and air emissions SDA).

The SDA was performed following the two approaches proposed by Sun and Dietzenbacher and Los, respectively. The same results have been obtained applying the two methods.

Furthermore, a sector level analysis leads to allocate the assessed indicators to the different economic sectors and also to identify which sectors are the most relevant sources of variation.

The study allowed to identify the key factors and the economic sectors causing the increase of the examined indicators, in order to give valid information to decision-makers to formulate strategic plans and relevant policies for mitigating energy and environmental impacts.

The results of the SDA point out that, in the most part of the sectors, the main influencing driving force is the final demand of goods and services, determining the highest effect to the increase of energy consumptions and often offsetting the benefits induced by E'_{effect} and L_{effect}.

Tertiary and "electricity, gas and vapour" sectors result the highest Italian consuming sectors of energy, so they should be the primary targets for any energy saving strategy. "Agriculture, hunting and sylviculture", fishing and air transports being energy intensive sectors should also receive attention.

The assessment of $CO_{2fossil}$ and other air emissions suggests to policy makers that one way to reduce indirect air emissions is to ensure a reduction of final demand, that is the main factor responsible of the emissions increase.

Then, the analysis stresses that to stabilise the emission levels the consumptions cannot continue to grow at a rate that is unsustainable for the environment. In fact, improvements in emissions intensity and in technologies at the moment are not sufficient to compensate for the impacts arisen from the evolving levels of consumption.

Another finding of the study, useful to plan the future environmental strategies, is that the "Agriculture, hunting and sylviculture" and "road and air transports" sectors, which are primarily sectors affecting air emissions, should be taken into account in strategies of environmental impact mitigation.

Finally, the results of the study stress that policies, which are aimed to reduce energy or emission intensity and to improve the technological structure of productive processes, cannot reach the expected environmental benefits if no change is brought in the final demand.

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